Museums working together: the atlas of the birds of Mexico

by Adolfo G. Navarro S., A. Townsend Peterson & Alejandro Gordillo-Martínez

SUMMARY

The present contribution is a case study of the application of data from world scientific collections to understanding the distribution, systematics and conservation of Mexican birds. Information was gathered on specimens from Mexico housed in 58 scientific collections in Mexico, the United States, Canada and Europe. This information was compiled in a centralised data base, and GIS programs used to visualise general geographic patterns and address historical patterns of ornithological investigations. We used the 'Genetic Algorithm for Rule-set Prediction' to predict current and potential distributional areas of species, patterns of species richness, endemism and seasonality, and conservation applications. The avifaunal inventory of Mexico is impressively thorough, but many areas are poorly represented in collections. Now, however, quantitative approaches to inferring into undersampled areas are available and offer many new insights into the biogeography of the region. These results suggest the possibility of developing new research products based on point-occurrence data from natural history museum collections.

RESUMEN

La presente contribución representa un estudio de caso de la aplicación de la información obtenida de colecciones ornitológicas de todo el mundo, para entender la distribución, sistemática y conservación de las aves de México. Se recopiló información sobre ejemplares mexicanos alojados en 58 colecciones científicas en México, Estados Unidos, Canadá y Europa. Esta información se conjuntó en una base de datos centralizada, la cual fue georreferenciada y se realizaron diversos análisis en SIG para visualizar los patrones geográficos generales y patrones históricos de la investigación ornitológica en México. Se usó el algoritmo GARP que, basado en los puntos de ocurrencia, permite realizar modelos predictivos de la distribución de las especies que involucran la construcción y descripción de las áreas de distribución actuales y potenciales de las especies, así como el estudio de los patrones de riqueza, endemismo, estacionalidad y aplicaciones en conservación. El inventario de la avifauna mexicana está muy avanzado, pero muchas zonas están poco representadas en las colecciones. Estos resultados sugieren la posibilidad de desarrollar nuevas investigaciones basadas en los datos de puntos de ocurrencias alojados en ejemplares de las colecciones.

Introduction

Mexico holds an astonishing biological diversity, ranking among the so-called megadiversity countries (Mittermeier *et al.* 1997). This richness originates in the geographic location of the country between two major biogeographic regions, Nearctic and Neotropical, that intergrade broadly in the area. Perhaps more importantly, the complex topography—coastal plains, mountain ranges, high plateaus, and islands—and geological history of the region produce a wide array of ecological conditions and favour the development of isolated populations and the action of *in* *situ* evolutionary processes. Thus, a high proportion of the biota of the country is endemic (Ramamoorthy *et al.* 1993).

In recent years, interest in surveying the biological resources of the country has increased greatly, with the goal of creating a national strategy to preserve biodiversity. Inventories and analyses of geographic, ecological, taxonomic and genetic diversity are key issues towards this goal (Soberón *et al.* 1996). Birds form important components of ecosystems, and are widely used as examples of what biodiversity studies *could* achieve because they are excellent ecological indicators and are well known taxonomically and distributionally.

To achieve these goals, the enormous quantity of information scattered across the world in the scientific literature and scientific collections must be assembled. Our main goal was to create a database aggregating data from Mexican bird specimens worldwide, and to develop analyses that illustrate the potential increase in understanding of biogeography, systematics and conservation of the birds of Mexico. We see this effort as a prototype for even broader efforts, eventually encompassing the entire world and numerous taxa, developed by the entire community of systematic biologists and biodiversity scientists in a massive collaborative effort.

The ornithological framework

Mexico is favoured with great bird diversity. Avian species richness, under the biological species concept, is estimated at 1,074, 107 of which are endemic to the country (Escalante *et al.* 1993, AOU 1998). Recent taxonomic revision, however, using alternative species concepts, has raised the number to 1,250 species, 229 of which are endemic (Peterson & Navarro 1999). Some of the endemic forms belong to 10 endemic genera (*Philortyx*, *Rhynchopsitta*, *Deltarhynchus*, *Rhodothraupis*, *Ridgwayia*, *Mimodes*, *Euptilotis*, *Hylorchilus*, *Calothorax* and *Xenospiza*), as well as genera recognised by some taxonomists, such as *Neochloe*, *Aechmolophus* and *Amaurospizopsis* (Friedmann *et al.* 1950, Miller *et al.* 1957). This richness is distributed in the country in very interesting patterns (Peterson *et al.* 1992, Escalante *et al.* 1993, Peterson *et al.* 1998): whereas highest species richness is concentrated in tropical regions in the south-east, endemism is highest in the islands, south-western tropical dry lowlands, and the mountains (Peterson & Navarro 1999).

Several species, both endemic and non-endemic, are considered globally threatened (BirdLife International 2000). Such taxa are often highly restricted geographically (e.g. Short-crested Coquette *Lophornis brachylopha*), inhabit highly endangered habitats (e.g. Horned Guan *Oreophasis derbianus*), or are threatened by hunting or illegal trade (e.g. Military Macaw *Ara militaris*). Six Mexican bird species are considered globally Endangered (Socorro Mockingbird *Mimodes graysoni*, Bearded Wood-partridge *Dendrortyx barbatus*, Short-crested Coquette *Lophornis brachylopha*, Guadalupe Junco *Junco insularis*, Black-capped Vireo *Vireo atricapillus* and Dwarf Jay *Cyanolyca nana*: BirdLife International 2000). An additional 13 species are listed as Vulnerable (e.g. Socorro Parakeet *Aratinga brevipes*, Maroon-fronted Parrot *Rhynchopsitta terrisi*, Nava's Wren *Hylorchilus navai*: BirdLife

International 2000). To date, extinctions include the Slender-billed Grackle *Quiscalus palustris* (Dickerman 1965), Guadalupe Caracara *Caracara lutosus* (Greenway 1967, Iñigo-Elías 2000a), and San Benito House Finch *Carpodacus 'mexicanus' mcgregori* (Jehl 1971). The Guadalupe Storm-petrel *Oceanodroma macrodactyla* and Imperial Woodpecker *Campephilus imperialis* are considered Critically Endangered (BirdLife International 2000) but are almost certainly extinct (Ceballos & Márquez 2000); and the Socorro Dove *Zenaida graysoni* is extinct in the wild. The Red-throated Caracara *Ibycter americanus* (Iñígo-Elías 2000b) and California Condor *Gymnogyps californianus* (Koford 1953) have been extirpated in Mexico (Ceballos & Márquez 2000, Ríos-Muñoz in press).

How do we know all this?

All of this information, constituting a basic resource for innumerable applications to wildlife conservation, is scattered across a multitude of sources (Peterson *et al.* 1998). Moreover, it is often unavailable to researchers, especially those in developing countries. Scientists and conservationists require information, including geographic locations of species' occurrences, ecological characteristics and conservation status, in order to develop research. The scientific literature is an important source, although biased by the fact that most formal publications on Mexican birds have appeared in foreign journals and in non-native languages, especially English, French and German (Rodríguez-Yáñez *et al.* 1994). A second and more widely distributed resource is that of field guides; these, however, are also generally in English and only provide generalities of the geographic range and ecology of species. Third, observations by birdwatchers and ornithologists would provide a rich resource, but are seldom published, organised, or made available in a useful fashion.

The most important sources of information regarding biodiversity are scientific collections (Peterson *et al.* 1998). The specimens that have accumulated through decades in many institutions worldwide constitute a critical baseline dataset for biodiversity studies. Indeed, the role of museums as caretakers and disseminators of this information, too often overlooked or underestimated recently, is gaining importance for several reasons. One is that the specimen record was obtained across diverse ecological and historical conditions, providing a rich record of past and present biodiversity phenomena. These specimens hold information relevant to identification, geographic location and historical distribution that can be *verified* by subsequent researchers. This basic reference and historical material for studies in avian systematics, ecology, evolution, genetics, biogeography, biodiversity, and conservation research and planning, thus have an enormous potential for diverse applications.

A bit of history

The history of ornithological investigations in Mexico was reviewed by Navarro (1989) and Escalante *et al.* (1993), and is summarised briefly here. Knowledge of the Mexican avifauna started with the indigenous cultures that inhabited the country.

At the time of the arrival of the Spanish *conquistadores*, most of the diversity of Mexican birds had been discovered by the people of different regions in Mexico, because birds played important roles in their daily activities, foods and religion. Monks and scientists from Spain, such as Fray Bernardino de Sahagún and Francisco Hernández, compiled indigenous knowledge on Mexico's natural resources (Alvarez del Toro 1985).

Further expeditions were made by the Spanish in the seventeenth and eighteenth centuries, and by French, German, British and Italian naturalists in the nineteenth century. On these trips, specimens were accumulated (as were field notes and paintings) that are now housed in Paris, Vienna, Berlin, Bremen, Cambridge, Turin, Madrid and elsewhere. The end of the nineteenth century saw the beginning of intensive exploration of Mexican biodiversity, particularly by English and U.S. scientists. Osbert Salvin and Frederic DuCane Godman coordinated the *Biologia Centrali-Americana*, a multi-volume description of Central American flora and fauna, of which four volumes were dedicated to birds (Salvin & Godman 1879-1904). The collections amassed were the product of fieldwork by themselves and by many collectors that they hired in the region, as well as by purchases of collections. Most of these specimens are now housed at the Natural History Museum in the United Kingdom.

Edward Nelson and Edward Goldman, from the United States National Museum in Washington, D.C., explored Mexico's natural resources as part of the United States Biological Survey. Thousands of bird specimens were accumulated, and updated information on ecology and biogeography of the species and communities was assembled (Goldman 1951). Their work sparked intense interest in the Mexican avifauna in the first half of the twentieth century. In this period, several professional collectors (e.g. Chester Lamb, Wilmot W. Brown, Mario del Toro Avilés) and researchers from many institutions in the United States and Canada visited different regions within the country and made important collections. The most important collections are those at the Moore Laboratory of Zoology, American Museum of Natural History, Field Museum of Natural History, Museum of Vertebrate Zoology, Museum of Comparative Zoology, University of Michigan and Louisiana State University.

More recently, several Mexican or Mexico-based researchers, particularly at the National Autonomous University (UNAM), further improved the knowledge of Mexican birds (e.g. Allan R. Phillips, Rafael Martín del Campo). Today, a young and active ornithological community is developing at many institutions, adding to the ecological, systematic and geographical knowledge of Mexican birds. Centres of ornithological research with important collections are located in Mexico City (UNAM and Instituto Politécnico Nacional), Monterrey (Universidad de Nuevo León), Morelia (Universidad Michoacana), and Chetumal and Tuxtla Gutiérrez (ECOSUR and Instituto de Historia Natural), among others. Given this history, the scattered and locally unavailable nature of information about Mexican birds is very clear; yet the need for such information is enormous, as many conservation-related initiatives are taking place in Mexico as part of regional and international efforts, as well as for basic research.

Methods

Data were obtained from 58 scientific collections in Mexico, United States, Canada and Europe (Table 1) with the generous assistance of curators at each institution, often by direct visits; of these datasets, information from 40 has been cleaned, standardised and incorporated into a single data resource (Fig. 1). Data were obtained in different forms, depending on the collection. We were able to obtain electronic copies of the holdings of 21 collection databases that were already computerised in various formats (Dbase, Excel, ACCESS or ASCII files). In very large and uncomputerised collections, we consulted the original collection catalogues and checked data against the actual specimens. A few collections were surveyed through the scientific literature, especially those for which catalogues of extinct, type or all specimens had been published. Most commonly, however, we captured data directly from the specimens, allowing checks of identification, locality, sex and age of the specimens. This capture and updating of data is an ongoing job, and several Mexican (e.g. ECOSUR) and foreign collections (e.g. Russian Academy of Sciences) are waiting to be included in the main database.

Records from scientific literature were obtained from an exhaustive survey of some 4,000 references on Mexican birds produced between 1825 and 1999 (Rodríguez-Yáñez *et al.* 1994). Specific occurrence records were drawn from 312 recent references (1986–1999) that updated the distributional information on many species, especially in poorly known areas (e.g. islands in the Gulf of California), and performed by observers that we deemed experts (e.g. E. Mellink, H. Gómez de Silva). This literature survey accounted for 8,900 individual georeferenced records (3.4% of the total records used for this contribution). A relational database was constructed that contained basic fields available from most specimens and bibliographic records (Fig. 2). For each record, taxonomy was updated to a recent version of the biological species concept (AOU 1998), as well as to a new treatment based on the phylogenetic/evolutionary species concepts (Peterson & Navarro 1998).

TABLE 1

Summary of 58 natural history museums contributing Mexican bird specimen records to the database described in this paper. Note that numbers reported represent the number of records in the *Atlas* database, and do not necessarily represent the total of specimens in the institution. Museums included in the analyses presented in this paper are indicated with asterisks (*) and n/a indicates information not available yet.

Institution	country	species	specimens
Moore Laboratory of Zoology, Occidental College*	USA	806	43,297
Museum of Comparative Zoology, Harvard University*	USA	958	21,261
Instituto de Biología, Universidad Nacional Autónoma de México	Mexico	n/a	24,000
Natural History Museum, Tring*	UK	889	19,386
Louisiana State University Museum of Natural Science*	USA	949	17,808
Delaware Museum of Natural History*	USA	891	16,711
American Museum of Natural History*	USA	907	15,803
University of Michigan Museum of Zoology	USA	800	13,312

Western Foundation of Vertebrate Zoology*	USA	858	12,597
Field Museum of Natural History*	USA	889	12,067
Bell Museum of Natural History, University of Minnesota *	USA	734	11,636
Museo de Zoología, Facultad de Ciencias, UNAM*	Mexico	672	10,431
Museum of Vertebrate Zoology, University of California*	USA	314	9,221
University of Kansas Museum of Natural History*	USA	762	8,504
United States National Museum of Natural History*	USA	672	8,296
Universidad Michoacana San Nicolás de Hidalgo *	Mexico	413	8,296
Carnegie Museum of Natural History *	USA	783	8,192
California Academy of Sciences	USA	611	6,655
San Diego Natural History Museum*	USA	451	6,518
University of California, Los Angeles*	USA	459	5,560
Cornell University Laboratory of Ornithology	USA	657	5,068
Canadian Museum of Nature *	Canada	534	4,643
Peabody Museum, Yale University*	USA	654	4,298
Muséum Nationale d'Histoire Naturelle, Paris*	France	633	4,016
Los Angeles County Museum of Natural History*	USA	633	3,364
Southwestern College, Winfield, Kansas *	USA	557	2,549
Florida Museum of Natural History	USA	535	2,326
Royal Ontario Museum*	Canada	551	2,188
Academy of Natural Sciences, Philadelphia*	USA	547	2,084
University of British Columbia Museum of Zoology*	Canada	267	2,016
University of Arizona*	USA	450	1,657
Texas Cooperative Wildlife Collections *	USA	324	1,347
Forschungsinstitut Senckenberg, Frankfurt	Germany	n/a	1,339
Museum für Naturkunde, Berlin	Germany	463	1,320
Museo de la Biodiversidad Maya, Campeche	Mexico	180	1,024
Übersee-Museum, Bremen	Germany	300	957
Denver Museum of Natural History*	USA	166	675
Museo Regionale di Scienze Naturali, Torino	Italy	n/a	632
Burke Museum, University of Washington, Seattle	USA	218	548
Staatliches Museum fur Naturkunde, Sttutgart	Germany	n/a	484
Museo Nacional de Ciencias Naturales, Madrid	Spain	186	470
Natuurhistorische Museum, Leiden*	Holland	137	327
Muséum Nationale d'Histoire Naturelle, Genève	Switzerland	n/a	307
Museum Koenig, Bonn	Germany	n/a	267
Museo La Specola, Università di Firenze	Italy	n/a	212
Zoologische Staatssammlung, Munich	Germany	n/a	210
Museo di Storia Naturale, Genova	Italy	n/a	206
Russian Academy of Sciences, St. Petersburg	Russia	n/a	196
University Museum of Zoology, Cambridge	UK	112	148
Fort Hays State College, Kansas*	USA	75	120
Manchester Museum, Manchester	UK	n/a	87
Nebraska State Museum*	USA	55	87
Museo Civico di Storia Naturale, Milano	Italy	18	23
Iowa State University, Ames*	USA	9	22
Moscow State University Museum	Russia	17	17
Darwin Museum, Moscow	Russia	9	9
Museo Federico Craveri, Bra	Italy	n/a	n/a

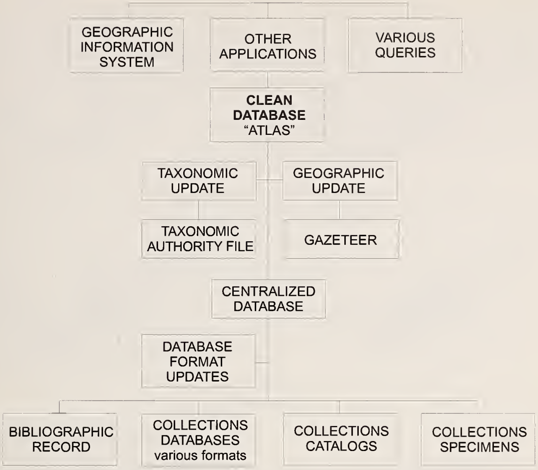

Figure 1. Sources and information flux in the *Atlas* database: raw data input is shown at the bottom, and updated and edit ascending in the middle; the resulting clean database and applications are shown at the top.

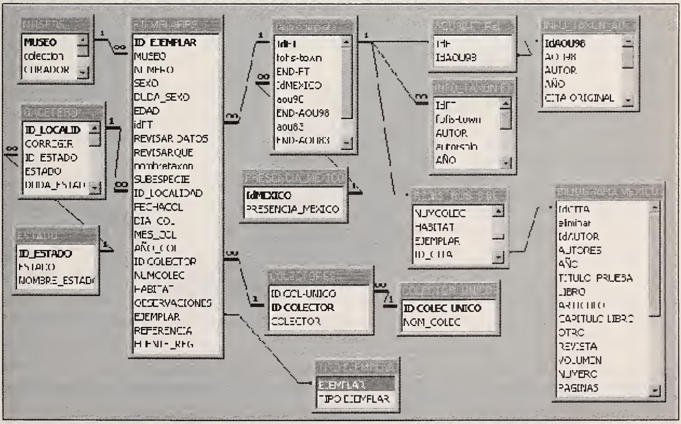

Figure 2. Relational structure of the *Atlas* database.

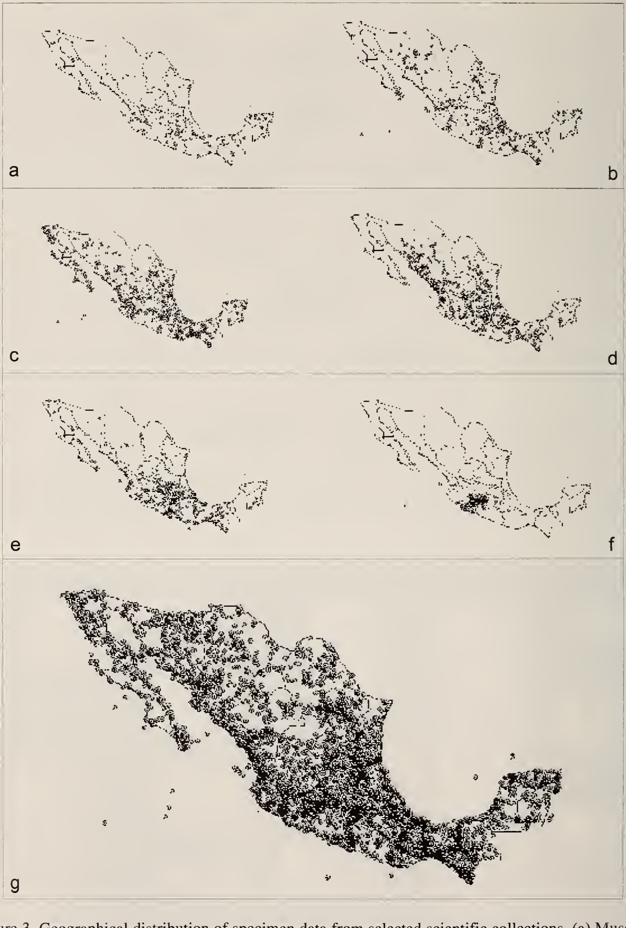

Figure 3. Geographical distribution of specimen data from selected scientific collections. (a) Muséum Nationale d'Histoire Naturelle, Paris; (b) American Museum of Natural History, New York; (c) Natural History Museum, Tring; (d) Moore Laboratory of Zoology, California; (e) Museo de Zoología, Facultad de Ciencias, UNAM, Mexico; (f) Universidad Michoacana, Morelia, Mexico; (g) sum of locality data from 40 institutions in the *Atlas* database.

Once records were captured, an extract of unique localities was performed to obtain a gazetteer or geographic authority file. This file included all unique combinations of state, locality and elevation. Latitude and longitude data (as decimal degrees) for each unique locality were obtained using 1:250,000 maps of the country (INEGI 1988). Correct locations of localities for which multiple sites had the same name in a state were determined with the help of published gazetteers (e.g. Paynter 1955) or original field notes. Of an initial total of more thyan 36,600 unique localities, 94% were successfully georeferenced.

Once the database was constructed, 248,000 of 250,000 records were selected. Those for which (1) identification and locality was not doubtful from 40 museums and (2) data had already been incorporated into the centralised database were used to develop the analyses that follow. To visualise general geographic patterns we used ArcView (ESRI 1999). Digital cartography was made available by the Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO). Analyses involving predictive distributional areas were performed using the Genetic Algorithm for Rule-set Prediction (GARP: Peterson *et al.* 2003, this volume).

Results

Representativeness of collections

How well represented are the birds of Mexico in each scientific collection? Biodiversity analyses require abundant information that is rarely available from a single data source. Particular collections specialise on a particular state (e.g. Universidad Michoacana), or have broader coverage (e.g. Moore Collection, Fig. 3), and indeed no single collection contains sufficient geographic or taxonomic representation to develop a full analysis (Peterson *et al.* 1998). However, accumulation of localities across the 40 data sets included in our studies leaves few major areas unsampled, providing much more complete ornithological information. Now, with increasing quantity and availability of observational information, visual records can complement the specimen record to provide further detail (Fig. 4).

Although this analysis may suggest that the avifaunal inventory of Mexico is satisfactorily complete, we plotted localities for which more than 100 specimens (an arbitrary measure) are available (Fig. 5). The resulting pattern is interesting because the gaps are much wider, and many areas of Mexico are clearly still poorly represented in collections. The database also provides a valuable resource for guiding systematic studies. For example, specimens of the different forms of Common Bush-tanager *Chlorospingus ophthalmicus* (Sánchez-González 1999) are scattered widely among institutions (Fig. 6). Using an information resource such as the one we have developed, a researcher may easily detect key specimens for a particular study, thereby maximising efficiency.

Distributional patterns

Georeferenced specimen occurrence data can easily be retrieved into geographic information systems applications, permitting association of biological data with

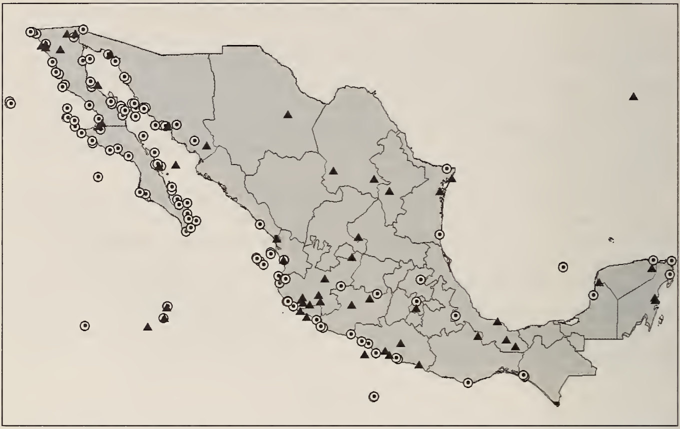

Fig. 4. Comparison of different sources of locality data, for a suite of aquatic birds (Procellariiformes, Gaviiformes and Pelecaniformes). Circles indicate specimen records, whereas triangles indicate visual records from selected literature sources.

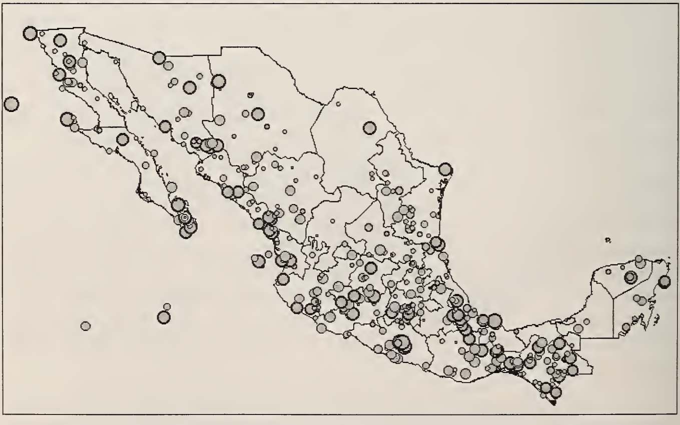

Figure 5. Localities from which more than 100 specimens have been collected, with different sizes of circles indicating increasing numbers of specimens (100 to 4,800).

geographic and ecological information available in digital formats. This analytical format offers a series of opportunities for understanding basic distributional phenomena, particularly with regard to predicting geographic distributions. For example, correlating known occurrence points of species with ecoregions (CONABIO 1999) provides a first idea of potential geographic distributional areas (Fig. 7).

More complex methodologies for estimating distributional areas from occurrence data vary widely (Udvardy 1969), both in approach and in results. Fig. 8 illustrates the application of two different methods to the same dataset for two species (García-Trejo *et al.* 1999). Most methods (e.g. Fig. 8b) depend overmuch on dense point coverage of known distributions for reconstructing areas. Given the paucity of records available for most species (Peterson *et al.* 1998), alternative methods that allow predictions of distributions based on incomplete knowledge are needed.

A powerful tool for extrapolating potential distributional areas from primary point occurrences has been developed by D. R. B. Stockwell (Stockwell & Noble 1992, Stockwell & Peters 1999), and is called the Genetic Algorithm for Rule-set Prediction (GARP). GARP uses an artificial intelligence approach (the genetic algorithm) to produce an abstraction of the ecological niche of a species, based on

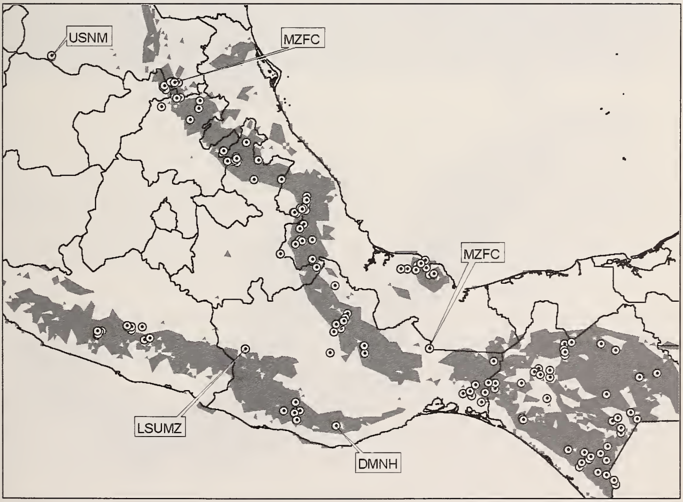

Figure 6. Localities of Common Bush Tanagers *Chlorospingus ophthalmicus* in Mexico. Labels indicate scientific collections in which selected specimens are housed. LSUMZ, Louisiana State University; DMNH, Delaware Museum; MZFC, Museo de Zoología, Facultad de Ciencias UNAM; USNM, United States National Museum. Shading represents the predicted distribution of the species modeled in GARP.

Figure 7. (a) Point locality data (black stars) for the endemic Bearded Wood Partridge *Dendrortyx barbatus* in Mexico, superimposed on a map of terrestrial ecoregions (CONABIO 1999). Areas highlighted are those holding cloud forest or humid pine-oak forest. (b) Map showing the Ecoregions (grey) (CONABIO 1999) in which the Stripe-headed Sparrow *Arremonops rufivirgatus* occurs according to distributional point data (white circles).

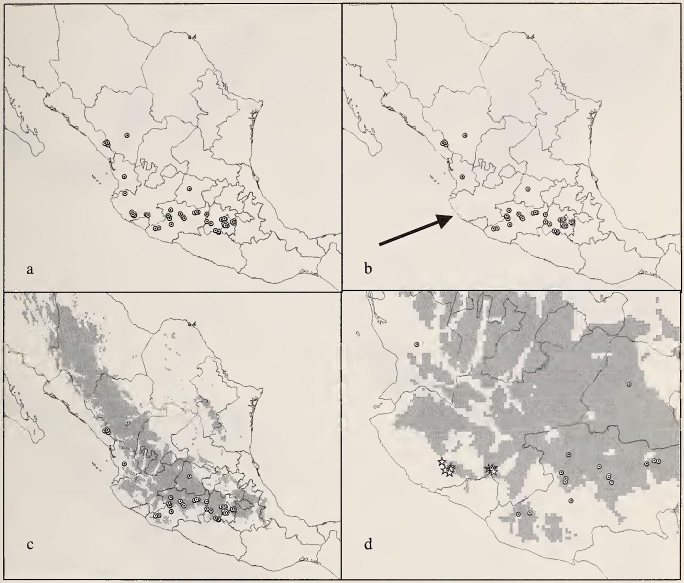

Figure 8. Models of the geographic distribution of an endemic Mexican species, the Stripe-headed Brush-finch *Buarremon virenticeps*: (a) primary point data drawn from the *Atlas* database; (b) removal of test points from the state of Jalisco; (c) GARP prediction of distributional area (predictive model built with data from Jalisco removed); and (d) close-up of state of Jalisco, showing correspondence between prediction and test dataset (stars).

physical and ecological attributes available in digital formats. An example is provided in Fig. 9, in which known occurrences of a species endemic to Mexico (*Buarremon virenticeps*) are used to predict its geographic distribution. Extensive testing of the predictive accuracy of models developed using this approach have amply demonstrated its utility (Peterson & Cohoon 1999, Peterson *et al.* 1999, 2002a,b, Peterson 2001, Peterson & Vieglais 2001, Anderson *et al.* 2002a,b, in press, Feria & Peterson 2002, Stockwell & Peterson 2002a,b).

Species richness, endemism and conservation

There are many potential applications of this information resource and technology to the conservation of biodiversity. For single-species prioritisations, Fig. 10 provides an illustration of the geographic situation of the Oaxaca Sparrow *Aimophila*

Figure 9. Use of primary data points for construction and evaluation of distributional areas: (a) data points for Thicket Tinamou *Crypturellus cinnamomeus*, *sensu* AOU 1998) from the *Atlas* dataset; (b) distribution based on ecoregions highlighted by point data; (c) buffer zones (10 km intervals) for estimating continuity of areas; (d, e) GARP predictions for the two phylogenetic species (*sensu* Navarro & Peterson submitted), Western Tinamou *C. occidentalis* and the eastern populations (*C. mexicanus*); and (f) distributions of northern subspecies (Friedmann *et al.* 1950).

notosticta, a species of conservation concern in Mexico. Indeed, modelling its geographic distribution only amplifies the concern for this species in Mexico, as the species proves to be left out of present conservation efforts entirely.

The predictive approaches of GARP can be applied to more complex challenges, combining results for suites of species. For example, Fig. 11 illustrates an overlay of the distributional areas of quail species endemic to western Mexico. Here, peaks and valleys in richness of endemic species can be detected, and can be incorporated in conservation planning; use of complementarity algorithms permits the development of quantitative conservation strategies (Gordillo-Martínez 2000).

Discussion

The principal source of information on the systematics and distribution of the Mexican avifauna as a whole are Friedmann *et al.* (1950) and Miller *et al.* (1957). Although a recent publication (Howell & Webb 1995) updates the distributional overview, it is in an extended field-guide format and does not provide detailed geographic information for most species. The vast dataset assembled in our work, including

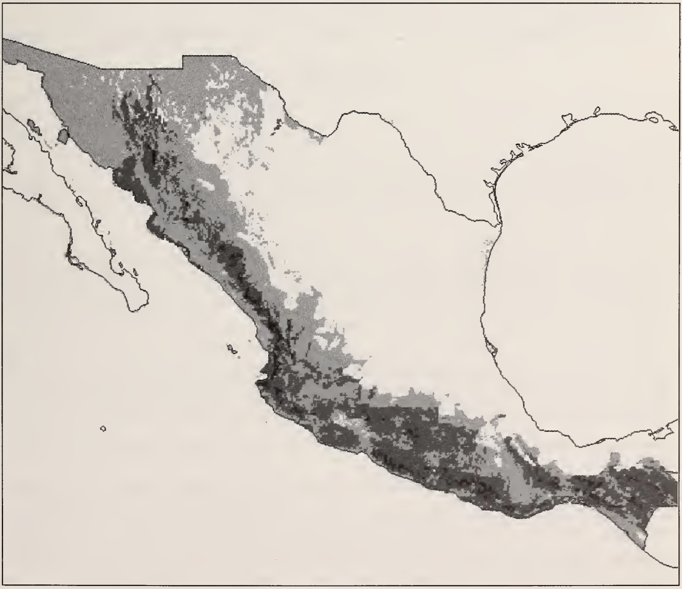

Figure 10. Overlay of potential distributional areas of quail species in western Mexico. Different shades of grey indicate high (black) to low (light grey) concentration of species. Data from Gordillo-Martínez (2000).

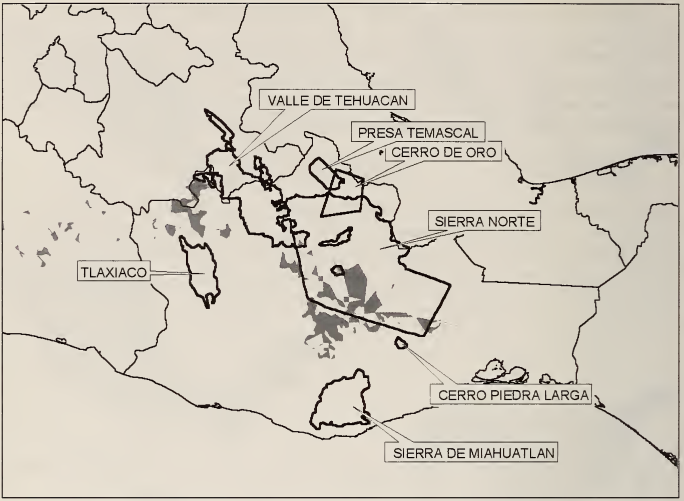

Figure 11. Predicted distributional area (solid grey) of a range-restricted endemic species, the Oaxaca Sparrow *Aimophila notosticta*. Polygons represent Important Bird Areas (IBAs) proposed for the region (Arizmendi & Márquez 2000). Note that only the Valle de Tehuacán Reserve is an area protected officially.

specimens, bibliographic records and some field observational data, forms the basis for our *Atlas of Mexican birds*, currently in preparation in collaboration with specialists around the world. This publication is based on a modern taxonomic treatment of the whole avifauna, and presents detailed analyses of the distribution of each species, as well as summaries of general patterns of species diversity, endemism, conservation status, and correlations with environmental and geographic features of the country. This work will serve as a model of how the bases for national biological surveys can be built from existing information held in the world's natural history museums, and will illustrate the many and varied potential uses of the information.

As one reviewer of this paper stated, 'the value of the kinds of work cited depends on the availability of the (raw) data … Publication of an atlas is all very well, but hard copy data are only marginally more useful than no data at all'. We heartily agree with this point of view. However, electronic 'publication' of the atlas database is neither feasible nor particularly desirable. Problems with feasibility stem from issues of permission to 'serve' data on specimens from a source that is not *at* the institution owning the specimens—several curators are rightly concerned about the implications for their institutions' rights to 'ownership' of data. Moreover, serving such a centralised dataset is not desirable: centralised datasets suffer serious problems with update—as collections databases are edited and corrected at the institutions where specimens are housed, the corrections are not passed on to the centralised data source. Hence, the best solution to the challenge of making these data—and biodiversity data in general—broadly available is not to serve centralised datasets.

A much better solution is that of distributed access to diverse biodiversity datasets. Here, centralisation is only achieved in a virtual sense. Rather, datasets are served by each of the institutions that care for, curate and document the associated specimens, and integrated virtually via the Internet. This design has the great advantage of keeping the data *at the institutions where the specimens are housed*. Three prototype distributed biodiversity networks now serve avian data: *The Species Analyst* (http://speciesanalyst.net), REMIB (http://www.conabio.gob.mx), and ENHSIN (http://www.nhm.ac.uk/science/rco/enhsin). A common technology that should unite these three networks and others is now under development (the 'DIGIR' project). Anticipated is a broad proposal to integrate many additional data sources (the 'ORNIS' [ORNithological Information System] Project!), which is in the process of preparation for submission to the U.S. National Science Foundation for funding.

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References:

Álvarez del Toro, M. 1985. Las aves. Pp.237-240 in Beltrán, E. Álvarez, T., Álvarez del Toro, M., Smith, H., Barrera, A., Hoffmann A. & Álvarez, J. *Historia de los animales de Nueva España*. Obras Completas de Francisco Hernández, 7. Universidad Nacional Autónoma de México, Mexico City.

American Ornithologists' Union. 1983. *Check-list of North American birds*. Sixth edition. American Ornithologists' Union, Washington, D.C.

American Ornithologists' Union 1998. *Check-list of North American birds*. Seventh edition. American Ornithologists' Union, Washington, D.C.

Anderson, R. P., Laverde, M. & Peterson, A. T. 2002a. Geographical distributions of spiny pocket mice in South America: insights from predictive models. *Global Ecology and Biogeography* 11: 131-141.

Anderson, R. P., Laverde, M. & Peterson, A. T. 2002b. Using niche-based GIS modeling to test geographic predictions of competitive exclusion and competitive release in South American pocket mice. *Oikos* 93: 3-16.

Anderson, R. P., Lew, D. & Peterson, A. T. In press. Evaluating predictive models of species' distributions: criteria for selecting optimal models. *Ecological Modelling*.

Arizmendi, M. C. & Márquez, L. (eds.) 2000. *Áreas de importancia para la conservación de las aves de México (AICAS).* Mexico City: CONABIO-Comission for Environmental Cooperation.

BirdLife Intenational. 2000. *Threatened birds of the world.* BirdLife International, Cambridge, U.K.

Ceballos, G. & Márquez-Valdelamar, L. (coordinators). 2000. *Las aves de México en peligro de extinción.* Instituto de Ecología, UNAM–CONABIO–Fondo de Cultura Económica, Mexico City.

CONABIO. 1999. Ecorregiones de México. Digital Map Scale 1:1 000 000. Mexico City.

Dickerman, R. W. 1965. The juvenal plumage and distribution of *Cassidix palustris* (Swainson). *Auk* 2: 268-270.

Escalante, P., Navarro, A. G. & Peterson, A. T. 1993. A geographic, historical and ecological analysis of land bird diversity in Mexico. Pp.281-307 in Ramamoorthy, T. P., Bye, R., Fa, J. & Lot, A. (eds.) *Biological diversity in Mexico: origins and distributions.* Oxford Univ. Press, New York.

ESRI. 1999. Arc View GIS Ver. 3.2. Environmental Systems Research Inc. USA.

Feria, T. P. & Peterson, A. T. 2002. Using point occurrence data and inferential algorithms to predict local communities of birds. *Diversity and Distributions* 8: 49-56.

Friedmann, H., Griscom, L. & Moore, R. T. 1950. Distributional check-list of the birds of Mexico: Part 1. *Pacific Coast Avifauna* 29.

García-Trejo, E. A., Ríos-Muñoz, C. A. & Navarro S., A. G. 1999. Corología de las aves de México, un enfoque metodológico. *Abstr. VI Neotrop. Ornithol. Congr.*, Monterrey, Nuevo León, México.

Goldman, E. A. 1951. Biological investigations in Mexico. *Smithsonian Misc. Coll.* 115.

Gordillo-Martínez, A. 2000. Modelling distributions of Mexican Odontophoridae: implications in conservation. Pp.79-85 in *Proceedings of the 2nd International Galliformes Symposium.* Kathmandu and Royal Chitwan National Park, Nepal.

Greenway, J. C. 1967. *Extinct and vanishing birds of the world.* Second (revised) edition. Dover Publications, New York.

Howell, S. N. G. & Webb, S. 1995. *A guide to the birds of Mexico and northern Central America.* Oxford Univ. Press.

Jehl, J. R. 1971. The status of *Carpodacus mcgregori. Condor* 73: 375-376.

Koford, C. B. 1953. *The California Condor.* National Audubon Society Research Report, 4.

Iñigo-Elías, E. 2000a. Caracara de Guadalupe (*Polyborus lutosus*). Pp.127-128 in Ceballos, G. & Márquez-Valdelamar, L. (coordinators) *Las aves de México en peligro de extinción.* Instituto de Ecología, UNAM–CONABIO–Fondo de Cultura Económica, Mexico City.

Iñigo-Elías, E. 2000b. Caracara comecacao (*Daptrius americanus*). Pp.126-127 in Ceballos, G. & Márquez-Valdelamar, L. (coordinators) *Las aves de México en peligro de extinción.* Instituto de Ecología, UNAM–CONABIO–Fondo de Cultura Económica, Mexico City.

INEGI (Instituto Nacional de Estadística, Geografía e Informática). 1988. Carta de México Topográfica 1:250,000. INEGI, México.

Miller, A. H., Friedmann, H. Griscom, L. & Moore, R. T. 1957. Distributional check-list of the birds of Mexico: Part 2. *Pacific Coast Avifauna* 33.

Mittermeier, R. A., Robles-Gil, P. & Goettsch de Mittermeier, C. 1997. *Megadiversidad.* CEMEX, Monterrey.

Navarro S., A. G. 1989. La sistemática ornitológica en México: posibilidades y limitaciones. In J. Llorente, ed. Los patrones de la evolución y la sistemática en México. *Revista Especial Ciencias* 3: 96-102.

Paynter, R. A. 1955. The ornithogeography of the Yucatan Peninsula. *Peabody Mus. Nat. Hist. Bull.* 9.

Peterson, A. T. 2001. Predicting species' geographic distributions based on ecological niche modeling. *Condor* 103: 599-605.

Peterson, A. T., Flores-Villela, O., León, L., Llorente, J., Luis, A., Navarro, A. G., Torres, M. & Vargas, I. 1993. Conservation priorities in Mexico: moving up in the world. *Biodiversity Letters* 1: 33-38.

Peterson, A. T., Escalona-Segura, G. & Griffith, J. A. 1998. Distribution and conservation of birds of northern Central America. *Wilson Bull.* 110: 534-543.

Peterson, A. T., Navarro, A. G. & Benítez, H. 1998. The need for continued scientific collections: a geographic analysis of Mexican bird specimens. *Ibis* 140: 288-294.

Peterson, A. T. & Navarro, A. G. 1999. Alternative species concepts as bases for determining priority conservation areas. *Conservation Biology* 13: 427-431.

Peterson, A. T., Ball, L. G. & Cohoon, K. C. 2002a. Predicting distributions of tropical birds. *Ibis* 144: e27-e32.

Peterson, A. T. & Cohoon, K. C. 1999. Sensitivity of distributional prediction algorithms to geographic data completeness. *Ecological Modelling* 117:159-164.

Peterson, A. T., Soberon, J. & Sanchez-Cordero, V. 1999. Conservatism of ecological niches in evolutionary time. *Science* 285: 1265-1267.

Peterson, A. T., Stockwell, D. R. B. & Kluza, D. A. 2002b. Distributional prediction based on ecological niche modeling of primary occurrence data. Pp.617-623 in Scott, J. M., Heglund, P. J. & Morrison, M. L. (eds.) *Predicting species occurrences: issues of scale and accuracy*. Island Press, Washington, D.C.

Peterson, A. T. & Vieglais, D. A. 2001. Predicting species invasions using ecological niche modeling. *BioScience* 51: 363-371.

Ramamoorthy, T. P., Bye, R., Fa, J. & Lot, A. (eds.) 1993. *Biological diversity in Mexico: origins and distributions*. Oxford Univ. Press, New York.

Rodríguez-Yáñez, C., Villalón, R. & Navarro S., A. G. 1994. Bibliografía de las aves de México (1825–1992). *Publ. Esp. Mus. Zool.* 4: 1-146.

Rzedowski, J. 1990. Vegetación Potencial. IV.8.2. Atlas Nacional de México. Vol. II. Escala 1:4000,000. Instituto de Geografía, UNAM. México.

Salvin, O. & Godman, F. D. 1879–1904. *Biologia Centrali-Americana. Aves*. Taylor & Francis, London.

Sánchez-González, L. A. 1999. Variación geográfica en morfología de las poblaciones mexicanas de *Chlorospingus ophthalmicus. Abstr. VI Neotrop. Ornithol. Congr.* Monterrey, Nuevo León, México.

Soberón, J., Llorente-Bousquets, J. & Benítez-Díaz, H. 1996. An international view of National Biological Surveys. *Annals Missouri Botanical Garden* 83: 562-573.

Stockwell, D. R. B. & Noble, I. R. 1992. Induction of sets of rules from animal distribution data: a robust and informative method of analysis. *Mathematics and Computers in Simulation* 33: 385-390.

Stockwell, D. R. B. & Peters, D. P. 1999. The GARP modelling system: problems and solutions to automated spatial prediction. *Internatn. J. Geographic Information Systems* 13: 143-158.

Stockwell, D. R. B. & Peterson, A. T. 2002a. Controlling bias in biodiversity data. Pp.537-546 in Scott, J. M., Heglund, P. J. & Morrison, M. L. (eds.) *Predicting species occurrences: issues of scale and accuracy*. Island Press, Washington, D.C.

Stockwell, D. R. B. & Peterson, A. T. 2002b. Effects of sample size on accuracy of species distribution models. *Ecological Modelling* 148: 1-13.

Udvardy, M. F. D. 1969. *Dynamic zoogeography*. Van Nostrand, New York.

Addresses: A. G. Navarro, Museo de Zoología, Facultad de Ciencias,Universidad Nacional Autónoma de México. Apartado Postal 70-399, México D. F. 04510, México. e-mail: fcvg01@servidor.unam.mx; A. T. Peterson, Natural History Museum, University of Kansas, Lawrence, Kansas 66045, U.S.A.; A. Gordillo-Martínez, Museo de Zoología, Facultad de Ciencias,Universidad Nacional Autónoma de México. Apartado Postal 70-399, México D. F. 04510, México